V E N T I L A T I O N

more particularly relating to

MECHANICAL VENTILATION IN PUBLIC BUILDINGS

by

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Regarding ventilation much has been written during the past thirty years, so that, by now a fairly large literature has accumulated. Theoretical considerations in the question of ventilation have been fertile sources of discussion but it cannot be said that the practical outcome has been of any very great value. The latter statement applies particularly to the ventilation of public buildings amongst which we include schools. Some of our most modern public buildings which have been ventilated by systems, which, on paper and for theoretical reasons, seem perfect, in practice have turned out to be utterly inadequately ventilated.

It is usual to blame the architect or the ventilating engineer for this failure, but a little consideration shows that neither is culpable. In nearly all cases it will be found upon examination that the ventilating expert has conformed to the standard required of him. He has introduced into the building a certain amount of air, he has maintained a fairly uniform temperature of the air whilst it is circulating in the rooms of the building, and the efficacy of his fresh air supply is measured by the amount of CO_2 found in the rooms when inhabited. If it be true then, that the engineer has come up to the standard requirements and that in practice we find such ventilation far from perfect, the only logical conclusion left is that the standard we have adopted is an inadequate one.

The object of this thesis is to review the subject and endeavour if possible to formulate a new standard.

EFFECTS of VENTILATION .

That an impure atmosphere reacts adversely upon health no one now denies. The investigations of Farr upon the relation of mortality to the density of population, of Tatham concerning the death-rate in back-to-back houses, and of Russell relative to the incidence of death in overcrowded rooms in Glasgow -- these are now classical. Carnelly, Haldane and Anderson in their famous experiments in Dundee found that, passing from 4 roomed houses to houses of 3,2 and I rooms, the air became more and more impure and that there was a similar and corresponding increase in the death-rate together with a marked lowering of the mean age at death : that the death-rate among children under five years of age in I-roomed houses was nearly four times as great as that in 4-roomed houses : and that the mean age at death in better class houses is almost twice as great as in I-roomed houses.

Other causes, as Newsholme points out in his Vital Statistics, may be operative, such as disease, poverty, evil social conditions etc. in producing an excessive mortality amongst the inhabitants of small houses.

Ogles researches have a distinct bearing on this point. He found that amongst agricultural labourers, fishermen, farmers and gardeners the death-rate from phthisis and respiratory diseases generally is about half that of the male community from these diseases, and that differences of food or housing accomodation could not account for the fact. He concluded that the outdoor life necessitated in these occupations accounted for the comparative immunity from respiratory diseases.

In this connection one naturally recalls the school room examples of the evils of lack of ventilation -- the Black Hole of Calcutta. The unfortunate prisoners who died there -- I23 in number -- were asphyxiated : they were deprived of their supply of oxygen.

We know now that even in the worst ventilated public buildings the oxygen is never diminished by more than I% of an atmosphere, and that, under these circumstances, there is always a sufficient pressure of oxygen to convert the haemoglobin of venous blood into oxyhaemoglobin.

Wherein then lies the evil influence of impure air ?

GASEOUS IMPURITIES of AIR .

The gaseous impurities which may be found in the air are chiefly carbon dioxide, ammonia in the form of salts, carbon monoxide, sulphurous acid and sulphuretted hydrogen. Ammonia is formed as the result of putrefactive processes and is generally found as ammonium carbonate or nitrate. In the most vitiated atmosphere these salts are never found in more than traces and they have no effect upon health. Carbon monoxide may find its way into the air in several ways. " Water gas" which is manufactured by passing steam over heated coke, contains as much as 40% carbon monoxide, so that such gas escaping into the air of an inhabited room would rapidly cause poisonous symptoms to supervene. Carbonic oxide is also formed as a product of imperfect combustion and may be given off in considerable quantity from stoves burning charcoal. Where large surfaces of heated metal are used to raise the temperature of the air in rooms, there is a danger of carbon monoxide being produced. The heated metal may convert part of the CO_2 of the air into CO , or the carbon of the cast iron may be oxidised, or particles of organic matter may be charred and oxidised. Complaints of headache are frequent in buildings which are heated by radiators and it is probable that such headaches are caused by carbon monoxide or by carbides which are given off in small quantities by the heated metal.

Carbonic oxide forms a very stable compound with haemoglobin and persons exposed to repeated minute doses of this gas will begin to suffer from the lack of oxyhaemoglobin. Most of the chemical reactions for estimating the amount of carbon monoxide are unreliable for the small amounts found in air, and in practice Haldane's method of determination with a blood solution is the most accurate.

In testing the air of mines a caged mouse may be used, a method which we also owe to Haldane who pointed out that a small animal such as a bird or mouse is affected by CO in about I/IO the time required to affect a man. In practice the mouse is exposed to the suspected air for I5 or 20 minutes and then killed by drowning. If more than ·OI% of carbon monoxide is present in the air, the blood of the animal when sufficiently diluted and compared with fresh normal blood similarly diluted has a more or less pink tint.

Sulphur dioxide occurs as a product of combustion and combines with the water vapour of the air to form sulphurous acid. It is formed in the air of rooms by gas burners and stoves. The amount present in the atmosphere can be estimated by aspirating a known quantity of air through a dilute solution of bromine water, precipitating the H_2SO_4 formed by ~~the~~ Ba Cl_2 and calculating the amount of SO_2 from the amount of Ba SO_4 obtained.

Sulphuretted hydrogen is found in collections of decaying matter, in sewer gas, and in the air of chemical works. This gas is poisonous and in the proportion of ·07 parts per IO,000 parts of air, it is dangerous to life.

Its amount may be estimated by aspirating a known quantity of air through a $\frac{N}{10}$ I_2 in KI Solution to which starch is added. $H_2S+I_2=2\ HI+S$.
Each c.c. I_2 Solution = I·7 milligram H_2S.

Carbon dioxide is found practically always in the atmosphere. In quantity it varies from 3 parts per 10,000 parts of air in the purest atmosphere to 20-30 parts per 10,000 in the air of crowded rooms. Expired air contains large quantities of the gas, sometimes as much as 450 parts per 10,000.

It is also a natural product of combustion and putrefaction. The usual method for estimating the amount of CO_2 in the air is Pettenkofer's. A known quantity of the air is shaken up with 60c.c. of baryta or lime-water, the alkalinity of which is determined before by titration with a standard solution of oxalic acid, using phenol-phthalein as an indicator. The oxalic acid solution is of such a strength that 1 c.c. exactly neutralises 1 milligramme of lime. The lime-water which is shaken up with the sample of air loses part of its causticity by reason of the conversion of part of the lime solution into carbonate of lime by the CO_2 present in the air, and consequently will require less oxalic acid to neutralise it. The difference between the number of c.cs. of oxalic acid solution required to neutralise the original lime-water solution and the number required to neutralise the lime-water shaken up with the air sample will give the amount of CaO lost in the original solution by its conversion into $CaCo_3$ by the CO_2 of the air sample and a simple chemical equation will give the amount of CO_2 present in the amount of air examined. The jar in which the air sample is collected must be dry and it is necessary to correct for temperature and pressure.

This method is not absolutely accurate but it is sufficiently so for all practical purposes and is convenient.

Haldane has devised an apparatus for the estimation of CO_2 which is, in reality, a eudiometer, caustic potash being used to absorb the CO_2. A narrow portion of the apparatus is graduated, each division representing $1/10,000$ part of the capacity of the burette, so that it is possible to read off from this the parts per 10,000 of CO_2 present in the air to be examined.

The apparatus is portable and as one can read off the portion of CO_2 present in the air directly it has been adopted by the Home Office for the estimation of CO_2 in factories etc. To get accurate readings one must have constant practice with the apparatus and certain precautions have to be taken to get accurate results as Haldane points out in his methods of Air Analysis.

After repeated trials I have never been able to use this apparatus satisfactorily.

One of the most unfortunate mistakes which has been made Sanitarians in considering the question of ventilation has been the adoption of the CO_2 content of the air as an index of its comparative purity or otherwise.

Many authorities are still obsessed with the idea that a pure and wholesome atmosphere must contain a low percentage of CO_2. As a matter of fact we have no evidence to prove that the amount of CO_2 as it occurs in the most badly ventilated rooms has any detrimental effect upon health. In breweries and in mineral water works it occurs in fairly large amount but the health of the work people in these works is not affected by it. Leonard Hill has shown that rats can live quite comfortably in an atmosphere containing 450-500 parts of CO_2 per IO,000. Indeed Haldane and Priestly have found that with a pressure of 2% of an atmosphere of CO_2 in the inspired air pulmonary ventilation of a man at rest was increased 50%, and with 3% about IOO%.

Nor is it possible to distinguish chemically the CO_2 given off in expired air from the CO_2 formed by combustion or by putrefaction.

The strongest argument for the retention of the CO_2 standard is that it affords a general index to the amount of organic impurity present in the air. Carnelly, Haldane and Anderson found that there existed a general relationship between the quantity of CO_2 and the organic matter, so that a high CO_2 content is, as a rule, accompanied by a high organic matter content and vice versa, " though this is by no means always the case ".

As will be pointed out later, there is at present no accurate method for estimating the amount of organic matter present in the air so that the above statement is not based upon any solid scientific foundation. Yet De Chaumont's figures are accepted to the present day and a room is considered to be sufficiently and efficiently ventilated if it contain no more than 6 parts of CO_2 per IO,000 of air.

This has led to the ventilating expert concentrating his attention upon this factor to the exclusion of other and probably more important impurities which may be present. Has it not been that the estimation of the amount of CO_2 present in the air is a comparatively easy matter, and has not too much been made of the relationship between a high CO_2 content and impure or unwholesome air ?

ORGANIC MATTER .

The nature of the organic matter which exists in a polluted atmosphere is not clearly known. It can be easily understood that small fragments of epithelium and fatty matter detached from the skin will go to form part of the organic matter in the air of an inhabited room. There are many other sources of organic matter of animal and vegetable origin -- e.g. débris from clothing, fragments of insects, vegetable fibres, moulds etc. That this organic matter which exists in the air is of importance from a hygienic standpoint can be readily understood for it will, and no doubt does form pabulum for micro-organisms. Many attempts have been made to determine the nature of this organic matter. In I888 Brown Sequard and d'Arsonval reported that condensed expired air when injected into rabbits caused rapid death and they attributed this to the organic matter contained in expired air, which they concluded was a volatile poison resembling in action a ptomaine. Later observers failed to confirm their

their results and it seems probable now that Brown - Sequard and d'Arsonval employed a faulty technique and that death was due to bacterial infection.

No accurate method has yet been discovered for estimating the amount of organic matter present in the air nor is it possible to distinguish chemically organic matter of human origin from that of animal or vegetable origin.

One method which has been commonly used is to aspirate a known quantity of air through doubly distilled ammonia-free water and then to estimate the nitrogenous matter present by Wanklyn's ammonia process. The ammonia present in the air of the room which is being examined must first be estimated by aspirating a known quantity of the air through ammonia-free-water and Nesslerising. The amount of ammonia found must be deducted from that found after distillation and Nesslerisation in the Wanklyn process.

There are three objections to this method. In the first place one must assume that all the organic matter of the air which has been aspirated through the distilled water has been arrested and this, obviously, may not be the case. On the other hand a fairly large fragment of hair or epithelium may be drawn into the water, in which circumstance an altogether excessive amount of ammonia will be given off and consequently an entirely erroneous estimate of the amount of organic matter present in the air will be formed. Finally, the injurious organic matter may not be nitrogenous.

Carnelly and Mackie introduced a simple method for estimating the organic matter in the air. A known quantity of the air to be examined is shaken up with 50c.c. millinormal solution of potassium permanganate and the amount of decomposed permanganate is deduced on colorimetric principles. To this method it can be objected that other substances besides organic matter reduce the colour of permanganate solution.. e.g. H_2S and Nitrites. On the other hand a certain proportion of any organic matter is oxidisable by permanganate but this amount bears no constant ratio to the total quantity of such pollution.

The organic matter in a room, being particulate, falls to the floor : the law of the fall of particles through air has been given by Sir G. Stokes. No solid or liquid particle is so small or light as to actually float in air. Consequently the organic matter together with inorganic particles is finally deposited as dust. It is obvious that air currents in a room may influence the rate of fall of these particles and that upward ventilation may by its dynamical effect be the means of supporting these for a longer period than would be the case in a room where the air was at rest. On the other hand downward ventilation will greatly increase the rate of fall and this may be taken advantage of as a hygienic measure. For instance some years ago it was not uncommon for the juteworkers in Dundee to suffer from tetanus. It was found that the spores of the bacillus were conveyed from India in the jute fibre. Mr Newlands, who was then H.M.Inspector of Factories for Dundee induced the millowners to adopt downward ventilation and since the installation of the latter tetanus has been of rare occurrence amongst the workers.

That dust may act mechanically upon the lung tissue producing pathological changes has been long known. Anthracosis and silicosis are examples of inorganic particles in the form of dust producing a chronic fibroid change in the lungs. Trades which involve working in an atmosphere heavily laden with dust always suffer from a heavy incidence of respiratory disease.

EFFECTS of BACTERIA .

The organic matter of the air is partly composed of bacteria, yeasts and moulds. Bacteria in their effects are much more deadly than the inorganic matter contained in dust which only acts mechanically. It is now beyond dispute that phthisis, pneumonia, diphtheria, influenza and pneumonic plague are contracted by the inhalation of the specific micro-organisms of these diseases.

A person infected with any of these diseases and compelled to lie in a room which is badly ventilated may well suffer from auto-inoculation, the air of the room becoming gradually laden with the bacteria of the disease.

May this not account for the excessive mortality from broncho-pneumonia in epidemics of pneumonia ? As has been pointed out by Medical Officers of Health time and again, the mortality rate increases with the density of population and with overcrowding. Little sufferers in single-roomed houses run far greater risk of death than those in four and five roomed houses. That the disease, in part at least, is due to auto-inoculation -- which after all means lack of ventilation-- is borne out by the fact that probably the best form of treatment is to get the patient out into the open air.

The final report of the Departmental Committee on Tuberculosis states that undoubtedly dirty (i.e. dusty), illventilated, dark, damp and unsanitary houses are provocative of the disease. And so, just as undoubtedly is this true of other diseases which are due to the inhalation of pathogenic micro-organisms. A person suffering from a disease of the respiratory tract produced by a definite bacterial infection in the act of coughing disseminates the specific germs throughout the air in his immediate neighbourhood. Flügge has shown this to be true of the tubercle bacillus, and it has become a stock laboratory experiment to infect the mouth with a growth of the bacillus prodigiosus, and by exposing plates containing a culture medium find out how far the bacilli can be projected in the act of coughing. It is not uncommon to find that the bacteria can be sprayed out to the distance of 20 feet from the observer. The bacillus prodigiosus is a particularly good organism for this purpose as, under ordinary circumstances it is non-pathogenic and its bright scarlet colonies easily distinguish it on incubation from the ordinary bacteria and moulds found in the air.

Pathogenic organisms are not readily detected in the air and it would be impractical to set out to estimate the number present in the air of a badly ventilated room. Whilst it is beyond dispute that the quaility of the micro-organisms present in the air is of more importance from a hygienic standpoint, nevertheless an excessive amount present in the atmosphere points to vitiation.

Tyndall in I878 pointed out that dust in the air might carry micro-organisms (the " raft theory ") and that dusty air contained more than dust-free air.

Several methods have been used for estimating the number of bacteria in the air. The oldest employed is that of Hesse, who used a long cylindrical glass tube coated inside with peptone gelatine. A known quantity of air is slowly aspirated through the tube the rate of flow of air never exceeding I litre in 3 minutes. The bacteria fall upon the gelatine in their passage through the tube and develop into colonies at room temperature. Carnelly, Haldane and Anderson adopted this procedure in their investigations in schools and dwelling houses in Dundee. They allowed their tubes to incubate until no more colonies showed, a period, generally of from three to four weeks. This fact accounts for the large numbers found by them.

One objection which has been raised to this method is that a particle of dust lighting on the gelatine may carry more than one organism but that only one colony will develope from such a particle. Another difficulty may arise from liquefying colonies running over the gelatine and obliterating colonies before they become visible.

Carnelly and his colleagues had to contend with this difficulty which they met by allowing for the number of colonies which might have been lost by this liquefying action. Other methods employed consist essentially in trapping the bacteria in filters of solid and sterile material. Thus Petri used sand as a filtering medium, the sand being subsequently mixed with liquefied gelatine, plated out and incubated. In the Sedgwick-Tucker method cane sugar is used for arresting the bacteria, the sugar afterwards being dissolved in liquid gelatine and a roll tube culture made. Frankland, in addition to finely powdered cane sugar, used glass wool as a filter.

In using sugar as a filter there are several technical difficulties. The sterilisation has to be most carefully carried out otherwise part of the sugar is converted into caramel, a substance useless for the purpose. The particles of sugar must be of a suitable size, for, if too small they will clog, and, on the other hand, if too large, they will not act efficiently as filters. In examining atmospheres which are moist the water in the air moistens the sugar and causes it to clog.

The simplest method of all, and one which gives equally good results, is to expose ordinary Petri dishes containing sterile agar or gelatine. Petri by experiment found that in five minutes the bacteria present in 10 litres of air are deposited on 100 sq.cms. of a plate.

This method was adopted in the following experiments which were undertaken in several of the schools in Dundee. Petri dishes with a superficial area of 20 sq.cms. and containing sterile agar were exposed for five minutes at desk level. The agar, which was made slightly alkaline with sodium hydrate, was sterilised in test-tubes and poured into the sterile plates. Batches of twelve plates were prepared at one time and two plates from each batch were taken at random and incubated to check any carelessness in technique. The plates were conveyed to the school in sterile envelopes. In all cases a desk in the middle of the room was selected : the pupils occupying the desk were asked to remove themselves and their belongings to another part of the room and a few minutes were allowed to minimise the disturbance of the air caused by the movement. Great care was taken in handling and exposing the plates to prevent as far as possible the risk of bacteria dropping on to the plates from the clothing of the observer. The plates were replaced in the envelopes and conveyed back to the laboratory and there incubated for 48 hours at 37°C.

The part of the glass capsule containing the medium was always placed uppermost in the incubator to prevent drops of condensation water dropping upon the medium and so infecting the surface. Agar was used as the culture medium, on the assumption that fewer saprophytic bacteria would grow on it than on gelatine, and that the organisms present were those capable of growth at body temperature and therefore more nearly approximate in number to the pathogenic organisms present in the air than would be shown by the number of colonies on a gelatine plate.

For purposes of comparison the schools are divided as to the method of ventilation existing-- natural or mechanical-- and in each case the number of persons present in the room and the cubic space in feet per person is given.

NATURAL VENTILATION.

Persons.	Cub.space per person.	Bacteria per litre of air.
58	I20	7·5
53	I32	4·5
56	I25	2
60	II6	I·5
50	I40	2·5
8I	I4I	9·5
8I	I39	IO·5
49	I39	4
45	2I7	4·5
47	2I7	5
37	I89	2
38	I84	I
46	IO4	I·5
48	I33	I
I8	466	I·5
55	I85	2·5
43	I64	2
44	238	8·5
66	I27	I7·5
78	I27	IO
40	24I	·5
54	I78	9·5
47	I78	I
48	I75	4·5
53	I24	IO
49	I77	I3
47	I43	I

Open air 7 per litre (School enclosed by dwelling houses).

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MECHANICAL VENTILATION .

Persons.	Cub.space per person.	Bacteria per litre of air.
59	I78	I
43	244	2
5I	I89	0
36	22I	0
56	I72	·5
55	I36	4·5
52	I45	2·0
4I	I84	0
28	I90	0
58	I30	2
48	I57	I
55	I90	·5
60	I6I	0
59	II0	4·0
4I	I36	3·5
42	233	I
30	266	I
42	I66	2
46	I6I	2
44	I75	3
24	29I	0
29	24I	I·5
4I	I70	6
36	I94	I·5

Hall.	0 per litre.
Open air.	0 " "
Tunnel.	·5 " "
Open air.	·5 " "
Dining Hall.	2·5 " "
Open air.	I " "

It is at once apparent, from the bacteriological standpoint, that mechanical is superior to natural ventilation, a fact which was demonstrated twenty years ago by Carnelly, Haldane and Anderson. The results above are not entirely comparable to theirs because of the difference in technique and in the medium used.

They found that in mechanically ventilated schools the micro-organisms diminish in a marked manner with the increase of cubic space. In naturally ventilated schools they found that the number of micro-organisms increased with a corresponding increase of the cubic space up to 250 cubic feet per person, after which the number diminished.

In the experiments just carried out I find no distinct relationship between the amount of cubic space and the number of organisms present : nor does there seem to be any relationship between the number of persons in the room to the number of micro-organisms.

The factor which is of importance is the amount of dust and a room giving a high number of bacteria would indicate an excess of dust. Tyndall's original experiments proved that a dusty atmosphere is rich in organisms, and this result has been confirmed by Miquel, Graham Smith, Andrewes and others. One is justified therefore in concluding that a wholesome atmosphere must be as free from dust as possible. The CO_2 content of the atmosphere bears no relation to the number of bacteria it contains, which was pointed out by Carnelly and his co-workers. This has been borne out by other observers. Naysmith, for instance, in examining the air of mines found in some cases a high percentage of CO_2 present in air which was practically free from bacteria and vice versa. If the amount of CO_2 in the atmosphere is no index of the amount of organic matter or the number of bacteria present, its retention as a standard of purity is almost indefensible more particularly when we recognise the fact that the amounts of CO_2 commonly found in overcrowded rooms has no influence upon health.

Would it not be more rational to fix a permissable limit of bacterial impurity of the air and, using a simple method of investigation, adopt this as a standard in preference to the present CO_2 standard ?

Quite recently M. A. Trillat has communicated to the Academie de Medecine some interesting observations regarding the influence of foul air on the growth of micro-organisms. (Lancet. Dec.I4th I9I2. p.I67I.) He found that bacteria exposed to vitiated air grew more rapidly than those exposed to pure air. An analysis of air vitiated by respiration showed it to contain ammonia, fatty amines and volatile substances similar to alkaloids. Gases given off from bouillon in which the proteus vulgaris was growing were found to give similar results. He also used as a culture medium distilled water containing $1/5,000,000$ part of its weight of putrid gas. These gases are given off in the decomposition of animal and vegetable substances.

M.Trillat's results have yet to be confirmed and it is interesting to note that Shattock failed to increase the virulence of a strain of diphtheria bacilli growing in bouillon over which sewer air was passed for a period of two months. (Trans. Path. Soc. 49. 1898.) However, granting that these experiments should be confirmed, this does not in any way strengthen the case for the retention of the chemical examination of the air as a standard of its purity. These putrid gases may be able to accelerate the rate of growth of bacteria in a vitiated atmosphere containing them but what really matters after all is the number of micro-organisms actually found to be present in such an atmosphere.

EFFECTS of WATER VAPOUR .

Air contains a certain amount of water in the form of vapour, and the water vapour present in the air of a room, under ordinary conditions, is equal to the amount of water vapour present in the outside air plus the amount added to it by the persons inhabiting the room. Expired air contains water vapour to the point of saturation, and, under normal conditions, each adult person per diem gives off about 10 ozs of water. Evaporation is constantly taking place from the surface of the body and the average normal adult loses about 30 ozs of water daily inthis manner. The rate and ease of evaporation from the skin surface has a very distinct influence upon the physical condition of the person. It is usual to measure the humidity of air indirectly by means of the wet-and-dry-bulb thermometer, the dew-point being found by means of Glaisher's tables. The maximum tension of the water vapour at the dew-point upon the maximum tension at the temperature of the air multiplied by IOO gives the relative humidity. The relative humidity is a per centage expression of the saturation of the air.

The whole subject of the humidity of the air and its influence upon health was investigated by the Home Office Royal Commission on Humidity and Ventilation in Cotton Weaving Sheds. The Report of this Commission is one of the most valuable issued in recent years. In certain processes in cotton spinning a moist atmosphere is a sine qua non for the proper working of the yarn, and this moisture in many cases was procured by pumping steam into the spinning sheds. The result was, that in these sheds the operatives were compelled to work in an atmosphere, high in temperature, and practically saturated with water vapour. Up till the time of the investigations of the Commission stringent regulations were enforced as to the permissable amount of CO_2 in these sheds-- more than 6 parts CO_2 per IO,000 parts of air was forbidden -- and no limit was placed upon the wet-bulb temperature. The operatives complained about the discomfort of working in these sheds and they also maintained that they were rendered susceptible to chills and respiratory diseases. Indeed the workers desired less ventilation so that the air of the sheds might become saturated with the moisture from their bodies and in this way render steam injectors unnecessary. Pembrey and Collis found that with a high wet-bulb temperature there was a tendency for the temperature of the body to become uniform --i.e. that the temperature of the skin surface approximated to the internal temperature of the body -- and that this threw a tax upon the heat-regulating mechanism, which was expressed by a rise in the pulse-rate and by a decrease in the blood pressure.

More elaborate experiments on the question of humidity have been carried out in London Hospital by Leonard Hill. He has constructed a small air-tight chamber, the capacity of which was 3 cubic metres of air. The chamber was fitted with observation windows, and contained electric heaters and fans. On one of the heaters a panful of water was placed to saturate the air with water vapour. In one set of experiments seven or eight students were shut in the chamber until the CO_2 reached 3-4% and the oxygen had fallen to 16-17%. The wet-bulb temperature rose to 80°-85° F and the dry-bulb a degree or two higher. The students' faces became flushed and moist and their breathing was deepened by the excess of CO_2 present in the air, but they had no headache. The discomfort which they suffered was relieved to a marked degree by setting one of the fans in motion. The movement of the air caused evaporation from the surface of the body, because, although the wet-bulb temperature was as high as 85° F, the temperature of the moisture on the surface of the skin and in the clothes was 98·6° F, -- body temperature. No relief was experienced by the students in the chamber when they were allowed to breathe pure air through a tube which connected the outer air with the chamber. Moreover, the observers outside experienced no discomfort from breathing the stale air of the chamber through a tube.

We are entitled to conclude from these experiments that an excess of moisture, together with a high temperature and want of movement of the air produce discomfort and oppression. It seems also a fair inference, that repeated and prolonged exposure to such an atmosphere, producing as it does changes in the pulse-rate and blood pressure, will be inimical to health.

Operatives in cotton sheds have been compelled to work in an atmosphere so saturated with water vapour and of such a temperature that evaporation from the surface of the body has been lessened. As a result the clothes and bodies of the workers become moist, which leads to much discomfort. On leaving such an atmosphere for one containing a less percentage of water vapour sudden evaporation takes place leading to chilling of the surface of the body.

Although the Commission came to the conclusion that there was no evidence to prove direct injury to health as a consequence of excessive humidity, they expressed the opinion that a long continuance of the bodily discomfort produced by such an atmosphere would probably result in injury to health.

The question of the humidity of the air, however, must be considered in connection with the temperature. Air saturated with water vapour but the temperature of which differs from body temperature by 30° or more, will, other things being equal, produce no sense of discomfort for the difference in temperature is such that evaporation can take place quite readily from the surface of the body. In other words, the nearer the wet-bulb temperature approaches 98·6° F, the greater will become the feeling of discomfort and oppression. As a matter of fact it has been found that to subject a person to an atmosphere, the wet-bulb temperature of which is 88° F, the air being still, causes a rise in body temperature even when the person is at rest. When the wet-bulb temperature exceeds 78° F, hard work becomes impossible. It is practically accepted now that a wet-bulb temperature of 75° F should never be exceeded, but that a temperature of 70° F is more desirable and below this there should always be a minimum difference between the wet-and-dry bulb temperatures of 2° F.

In the majority of cotton sheds the humidity was found to vary between 70% and 80% of saturation, which is by no means excessive. Indeed in a number of readings I have taken in the schools here this amount has been exceeded.

NATURAL VENTILATION .

Number of persons in room.	Cub. ft. per person.	Dry Bulb temperature.	Relative humidity.
8I	I4I	65°	78%
8I	I39	64°	82
49	I39	64°	82
45	2I7	65°	93
47	2I7	63°	89
37	I89	66°	90
38	I84	67°	84
46	I04	66°	67
48	I33	66°	56
I8	466	64°	70
55	I85	68°	65
43	I64	64°	67
44	240	64°	62
66	I30	63°	62
78	I30	64°	62
40	240	65°	62
54	I77	65°	58
47	I78	63°	72
48	I75	64°	67
53	I24	65°	67
49	I77	62°	77
47	I43	60°	80

MECHANICAL VENTILATION .

Number of persons in room.	Cub.ft.per person.	Dry-bulb temperature.	Relative humidity.
59	I78	60° ¥	77%
43	244	59°	77
5I	I89	59°	86
36	22I	62°	67
56	I72	60°	77
55	I36	58°	80
52	I45	58°	80
4I	I84	59°	80
28	I90	59°	80
58	I30	60°	74
48	I57	60°	86
55	I90	60°	83
60	I6I	6I°	86
59	II0	60°	80
4I	I36	59°	80
42	233	59°	80
30	266	59°	75
42	I66	60°	80
46	I6I	60°.	80

These observations taken at the same time as the air was examined bacteriologically, were made during the summer when the heating apparatus was not in use in the schools. It is noticeable that the relative humidity in the mechanically ventilated schools is higher than that of the naturally ventilated schools, and also that it varies less in the former.

METHODS of VENTILATION .

The oldest and simplest method of ventilation is that known as"natural ventilation".

Ventilation, from a mechanical point of view of whatever kind, resolves itself into a consideration of pressures. It is obvious that the pressure of the inflowing air must be greater than the pressure of the air in the room which is being ventilated : and also that the pressure of the air in the room must be greater than that of the air flowing out of the room. For an efficient scheme of ventilation we require a descending scale of pressures.

In natural ventilation this is produced by a.) the velocity of the wind, which, passing over the openings of flues or outlets connected with the interior of the room, causes a negative pressure in the flues and this suction action induces a movement of air through the room : or b) the difference in pressures may be obtained by maintaining the temperature of the air of the room or of the air in out-let channels, at a higher point than that of the outside air.

Natural ventilation which has to depend upon the action of the wind, is very uncertain. The use of open windows, Tobin tubes, vertical flues and cowls is founded upon the action of the wind.

On the other hand the usual method of ventilating a room naturally by means of a difference in temperature between the air of the room and the outside air, is by a fireplace. The heated air in the chimney extracts the air from the room, fresh air gaining entrance by windows doors and accidental openings. In place of a fire, heated flues have been used to convey warm air to various parts of a building, but such an arrangement possesses the serious disadvantage that, in certain states of the atmosphere, the whole system may be reversed and as a result there is a total failure to efficiently ventilate the building. Moreover this is a costly method and even a moderate wind can generate far more pressure than can be set up by the difference in temperature in the air of the flues.

It was this element of uncertainty which induced ventilating engineers to turn their attention to the question of ventilation by mechanical means.

By mechanical means ventilation is rendered certain : a definite and large interchange of air can be secured in all states of the weather and under all circumstances. Fresh air may be propelled throughout the building (plenum system) or the foul air may be extracted (vacuum system). Mechanical ventilation involves the use of fans and also the construction of flues of suitable size and shape throughout the building, and therefore is more costly than natural ventilation.

Neither the plenum nor the vacuum system is by any means perfect. To make the former as nearly perfect as possible all possible disturbances of the air currents caused by open windows, doors or chinks, must be reduced to a negligable quantity and this is found to be impossible in practice. Very often the whole system of ventilation in a building is destroyed by the careless opening of a window. Another grave disadvantage of the plenum system is that the increased internal pressure in the rooms of a building so ventilated causes the walls in course of time to be permeated by dust, bacteria etc. which leads to the rooms being unhealthy. In the newer buildings ventilated on this plan, this danger is counteracted by the provision of outlet flues which are collected into a common flue in the roof. There are, however, two objections to these flues, particularly in schools. They very readily transmit sound, and there also is the risk of air from one room being syphoned over into another. The latter action can be prevented by providing an extraction fan in the common flue in the roof.

The vacuum or extraction system is also open to several serious objections. It is never easy to manage, and there is no control over the entrance of air, and, as a consequence it is impossible to prevent dust finding its way into the rooms. As the air has to gain entrance by every casual opening, it may come in some cases from objectionable sources--e.g. W.C's. Another difficulty lies in the fact that there is always an inequality in the movement of the air from the rooms, the movement being strongest in the rooms nearest the extraction shaft and weakest or entirely absent in those most distant.

Theoretically, the ideal system would seem to be a combination of the plenum and vacuum methods, the fans being so adjusted as to maintain an equal flow in the inlet and outlet so that there would be no difference of pressure throughout the system.

Mechanical ventilation of whatever kind is always liable to break down from engine defects and it must always suffer on the score of cost. If, however, by increased expenditure we can ensure a sufficient supply of fresh wholesome air, surely the gain in health and efficiency will outweigh pecuniary considerations. This should be true particularly of schools because boys and girls at the period of greatest growth have to spend 6 hours daily in class-rooms, and this for a minimum period of 9 years.

SOME PRACTICAL POINTS in MECHANICAL VENTILATION .

That mechanical ventilation has failed to fulfil all that has been claimed for it is evidenced by the fact that at the present time there is a growing tendency to revert to natural ventilation. Yet, by mechanical ventilation, the whole air of a building may be easily changed in fifteen minutes, and, for the most part, the ventilating engineer has supplied us with air well up to the accepted standard of purity. Either the standard of purity which we have adopted is too low, or there are other factors of importance which have been left out of calculation. Probably there is a little of the truth in both hypotheses.

An inspection of several mechanically ventilated schools provides material for suggestive criticism.

In the older plenum ventilated schools the position of the inlet was evidently deemed of little import for several are found at ground level. The result of such an arrangement is that the air which is drawn in, is heavily laden with dust and this air, in nearly every case without screening, is propelled throughout the building. In most cases screens had originally been provided but these became so rapidly clogged as to be unmanageable and were discarded. More recently constructed schools which are ventilated on the plenum system have a brick-built air inlet which is roofed and stands about IO feet above the level of the ground. This prevents the entrance of grosser particles of dust into the air channels but it seems desirable notwithstanding to screen the air before driving it throughout the building. The question of screening is a vexed one and although one reads of the different forms of wet and dry screens they are seldom seen in working order. What actually happens in practice is that the screens become in time clogged, and, offering an increasing resistance to the inflow of air, instead of being cleaned they are discarded.

Dry screens are usually made of cotton wool between two layers of wire gauze of a fine mesh : these clog quickly and require to be cleaned frequently and they must be of large area. Wet screens are mostly made of woven fabric, or of coke or pebbles, and water is allowed to trickle over the surface of the screen continuously. Galton describes a screen in use in the Victoria Infirmary, Glasgow. (Hospital Construction p.63.) It is made of cocoanut matting and is automatically cleansed by a flush of 20 gallons of water every 24 hours. Some such device for automatically cleansing the screen seems desirable, for janitors and caretakers evidently will not take the trouble to clean them. Another method for removing the dust in plenum ventilated buildings is to subject the incoming air to a very fine (atomised) spray of water : each particle of dust is wetted and is arrested on baffle plates which are placed in series for this purpose along the main air channel. This method is open to two objections, viz. that the air may be rendered too humid, and that the baffle plates offer an increased resistance to the flow of air.

Plenum ventilation certainly offers this advantage over others that it allows of an opportunity to screen the air and so deprive it of dust. Even though it involves increased expenditure for the cleansing and renewal of screens there is as much justification as for spending money on the filtration of our water supplies. The probability is that bacteria-free air is of as much importance hygienically as bacteria-free water.

The failure of the system of ventilation in the Houses of Parliament is no doubt due in part to the fact that, although the air is carefully screened at the inlet, it is introduced into the Chambers through the floor and is thus contaminated at its point of entrance.

This brings us to the consideration of the fact that the screening of air before its introduction into the rooms of a building will not prevent the presence of dust. Dust is conveyed into rooms by the feet and clothing of the persons who inhabit the rooms.

Various preparations are on the market as dust preventers or rather dust-layers. These consist of an emulsion of oil with which the floors are sprinkled and brushed, the emulsion being allowed to dry upon the floor. It is claimed for them that they do away with the necessity for frequent washing of floors and also that the floors can be swept without first having recourse to wet sawdust or a similar preparation to keep down the dust. Two years ago I made some experiments with these preparations, exposing plates of agar at desk level for 5 minutes as in the experiments previously described. Two rooms of equal size in the same school were taken and, as far as possible, the same number of scholars occupied each room. One room was treated with the dust layer and the other was used as a control. The latter room was washed and swept in the ordinary way. Seven days after the application of the dust-layer agar plates were exposed in both rooms. The children in each room were asked to stand up and stamp their feet upon the floor thereby raising as much dust as possible. The plates were incubated for 48 hours at 37° C and then counted.

The plates which were exposed in the room treated with the dust layer contained colonies in such numbers as to be uncountable, the plates from the control room having a much fewer number. It may be objected that this test was unnecessarily severe but it is not an unpractical one. It is quite usual in the schools here to allow the children to stamp their feet on the floorfor a few minutes after each interval : a fairly large percentage of the children are barefooted and this allows them to warm their feet. The conclusion which one naturally draws from the results of these experiments, is, that these dust layers cause the dust and bacteria to adhere to the floor : they are unhygienic and even dangerous in that they seriously increase the bacterial content of the room. There are other, less formidable, objections to the use of these emulsions. They darken the floors and make them look dirty : they soil the skirts of the lady teachers : and in warm weather the smell of the oil is most oppressive.

At the same time I tested a dust layer which seemed to be composed of sand with an antiseptic added. This was to be used in sweeping floors and it was claimed for this preparation that it was superior to wet sawdust etc. Two rooms of equal size were taken and as far as possible the conditions in each room were similar. One room was sprinkled with the sand and then swept, the other with sawdust moistened with an antiseptic solution. Ten minutes after the sweeping was completed plates of agar were exposed for 5 minutes at floor-, seat- and desk-level. In each plate exposed in the room treated with sawdust there was a fewer number of colonies than in the corresponding plate exposed in the other room. The routine method of the cleaners in the Dundee schools, using moistened sawdust, seemed to be superior to the other.

The dust which is carried into the rooms by persons occupying them must be got rid of by cleanliness. Long ago Carnelly pointed out that cleanliness had an enormous influence upon the number of micro-organisms, and the Scotch Education Department having been impressed by the lack care in the matter, have issued a set of regulations for cleansing and disinfecting schools.

Returning to the consideration of plenum ventilated buildings, it strikes one upon inspection that the main inlet channels are not so well made as they might be. In most cases they are constructed of undressed stone and are not impervious to ground air. The rough stone must offer considerable resistance to the passage of air from friction, and, at the same time, the depressions and crevices in and between the stones become receptacles for dust. The amount of dust in these tunnels is quite surprising. It should surely be possible to construct these main shafts of some smooth impervious material which could easily be cleaned.

The branches leading off from the main channel are, in practically every case, at right angles to the latter, and the ducts leading to the rooms are too small. The angle of the branches and the small size of the ducts leads to am enormous loss of power by reason of the resistance offered. Moreover, in many cases the ducts are not of the same size throughout and it has been forgotten that the efficacy of the duct as an inlet is to be measured by its narrowest section.

In most instances no doubt the ventilating engineer is not to blame for this condition of affairs because he has to conform to the plans of the architect.

As far as possible the branches from the main tunnel should run at an obtuse angle and the ducts should be of uniform size throughout.

Instances are found every now and then of the elementary laws of pneumatics being disregarded. To double the supply of air to a room the most economical method is to increase the size of the inlet, but how often in practice is it deemed necessary to increase the power by introducing a larger fan. As a matter of fact by doubling the size of the inlet the flow of air is increased four times, but if the inlet remain of the same size to double the inflow means increasing the power eight times, which latter entails a great waste of energy. Air inlets should therefore be as large as possible. Indeed Thomas states that $\frac{3}{4}$ of the ventilating pressure is used up in friction due to the small apertures through which the air is forced. (Ventilation of Churches. p.I3).

Another practical difficulty in the ventilation of public buildings and that of schools in particular arises from the large window area. The heated air of the room coming into contact with the cold window surface, condenses and a down-draught results. This could be obviated by the provision of a heating surface along the bottom edge of the window, a method which would answer very well in a building ventilated on the plenum system. On the other hand, were the building ventilated by means of a plenum and vacuum system combined, the lower ledge of the window would form a very suitable place for an outlet.

The temperature at which the air should be introduced into the rooms is a matter of very great importance. It is very often forgotten that each person in a room acts as a radiator, and that the mere presence of a number of people in a room raises the temperature of the air. If a person receive an allowance of I cubic foot of air per second, it will be 4° F warmer when it leaves him than when it reaches him. (Shaw. Air Currents and Laws of Ventilation p.57.) Mechanically ventilated buildings with a central heating system are nearly always overheated from the fact being overlooked that the persons occupying the building contribute to the heating. The air should be introduced into the rooms at least 4°F lower in temperature than that desired in the rooms.

The convection currents which arise from the bodies of persons in a room, increase the difficulty of ventilation but at the same time efficient ventilation would be impossible without convection. Were it not for these currents the air of a room would tend to become of a uniform temperature, which is most undesirable. As Dr Boycott points out the freshness of the air in a room depends upon the fact that it is not of a uniform temperature, but that the air is broken up by draughts which come in contact with the surface of the body, lowering the temperature of the skin by promoting evaporation. Mechanical ventilation is fairly effectual in overcoming the resistance of these convection currents so that the air of the rooms tends to become of a uniform temperature, pockets of stagnant air are formed in the corners of the rooms as a consequence and no doubt the feeling of staleness in these rooms is due in part to the lack of the draughts which Dr Boycott refers to. The rate of movement of air currents is usually measured by anaemometers but those in common use with metal flanges are quite unsuitable for measuring or even detecting the lighter currents of a room. For this latter purpose Shaw has introduced an anaemometer with flanges of mica which indicates the slightest movement of the air. This instrument can be used for mapping out the air currents of a room and is particularly useful in indicating parts of the room where the air is at rest. Pockets of stagnant air are obviously undesirable and no room should be considered to be properly ventilated unless it be thoroughly and constantly swept by air currents. Rather than allow stagnant air to persist in corners of rooms, radiators or fans should be introduced to promote a free movement of air.

That those who are compelled by reason of their occupation to live for part of each day in rooms mechanically ventilated are prone to suffer from catarrhal diseases of the air passages and from sore throat, is a matter of common knowledge. This is usually attributed to the dryness of the air of these rooms. I have not been able to satisfy myself that this is the case. The air of mechanically ventilated rooms on an average seems to be as humid as that of naturally ventilated rooms. Expired air and evaporation from the surface of the skin are sufficient to make up for the moisture of which the air may be deprived by a central heating system.

I am distinctly of the opinion that the uniformity of temperature of the rooms and consequent stagnation of air lead to a slow rate of metabolism and at the same time favour bacterial growth. In other words persons living in rooms mechanically ventilated run the risk of a diminished immunity and at the same time they are exposed to the increased risk of infection.

It has been proposed to lessen this risk of bacterial infection in plenum ventilated buildings by adding ozone to the air. Indeed the Ozonair Company, Ltd., who are the patentees of the process, have installations at work on the Central London Railway and in several large public buildings. The air is drawn from as pure a source as possible, screened, and passed to a mixing chamber where the ozone is added : the ozonised air is carried by means of ducts to the various parts of the building or station etc.. It is claimed that by this process the air is purified, and that this is the result of the oxidation of deleterious organic matter by the ozone. The air of a building ventilated by this method certainly smells fresh and sweet, but this is probably due to the fact that ozone is a powerful deodorant. So far as we know ozone has no effective selection for bacteria and consequently much of its energy will be wasted in oxidising organic matter other than micro-organisms. Ozone, to act as a germicide, would require to be in such a concentration in the atmosphere as to be decidedly dangerous to health. The good results claimed for this method of ventilation may be attributed to the careful screening of the air and to the deodorant properties of the ozone.

For the sake of comfort we like our rooms to have a temperature in the neighbourhood of 60° F. In other words, we clothe ourselves indoors to suit such a temperature. This question of temperature, being so closely related to our physical feelings, induces janitors and caretakers to pay paramount attention to the heating of rooms. Indeed the average person is as much to blame, for he will endure stale and muggy air if the temperature of the room be comfortable.

How often do janitors point with pride to the fact that the temperature in their rooms varies but a degree or two from 60° F ? Yet this is a condition of matters by no means desirable. The nearer the temperatures in the different rooms approximate each other, the more uniform is the temperature of the air as a whole and the greater the danger of stagnation. Differences in temperature, on the other hand, are desirable, in that they promote movement of the air.

The introduction of electric lighting into buildings has increased this difficulty, for, although gas jets materially add to the chemical impurities of the air, they possess this advantage, that they create currents in the atmosphere which is not the case with electric light.

The windows of most schools which are mechanically ventilated are kept locked, and in many cases, in order that the entire system of ventilation may not be upset, the teachers are not provided with keys. The consequence is that the windows are seldom or never opened during intervals to flush out the rooms with fresh air. This is one of the gravest disadvantages of the plenum system and one which could be overcome by a carefully adjusted combination of the propulsion and extraction methods.

Finally, together with the ventilation and heating of a building must be considered the question of lighting. Sunlight is essential for every inhabited room which is to be healthful. The rays of the sun provide the cheapest and most efficient germicide we possess and for this reason alone we ought to flood our rooms with sunlight. Moreover the heat of the sun's rays beating into a room sets up air currents which assist in that movement of the air which is so essential to health.

Due regard must therefore be paid to the orientation of buildings and a sufficient window area should be insisted upon. It has to be remembered, however, that a large window area increases the difficulty of efficient ventilation, and that care must be exercised to strike the happy medium. Dr Thorne reporting upon the ventilation of the Childrens Hospital at Pendlebury states that the failure to maintain the ward air of that institution equably warm and at the same time sweet, was to a great extent due to the excessive window surface. It is obvious that this difficulty is more likely to arise in hospitals than in schools or other public buildings.

PROPOSED NEW STANDARD OF VENTILATION .

That so many of our public buildings are badly ventilated, I believe is due to the fact that our present standard is not the best possible. In nearly all cases the ventilating and heating engineer has come up to the specifications set him so that he is not to blame for the failure. We must alter our specifications.

From the outset we recognise that comfort is not the only criterion of good ventilation. Comfort is entirely a personal matter, and, as Shaw puts it " one man's fresh air is another man's draught". No matter how excellent the system of ventilation be, complaints are sure to be made.

The one essential of good ventilation should be that it provide a supply of wholesome, health-giving air.

Up to the present time the percentage of CO_2 in the atmosphere has been taken as a standard of its purity or otherwise. As we have already seen the CO_2 of the most polluted air has no direct effect upon health, neither does the percentage of CO_2 in the atmosphere bear a constant ratio to the amount of organic matter or to the number of bacteria to be found in the air. Indeed the retention of the CO_2 content of the air as a standard seems quite indefensible if we can offer another and more reliable standard.

In the light of present knowledge we are quite justified in saying that the chief danger of a vitiated atmosphere lies in the number of micro-organisms which such an atmosphere contains. At the same time we know that the more dusty the air is, the larger will be the number of bacteria. Therefore we are entitled to conclude that the first essential of a pure atmosphere will be its freedom from dust, and consequently the first demand we shall make of the ventilating engineer will be a supply of air as free from dust as possible. The latter will naturally insist upon the thorough and frequent cleansing of rooms to aid him in maintaining the standard.

The most efficient method for testing the freedom of the air from dust will be by a simple bacteriological examination such as has been described. This has the additional advantage of being a quantitative estimation of the number of micro-organisms in the air.

Using this procedure, it would not be too stringent a standard to regard IO micro-organisms per litre of air as the permissable amount of bacterial impurity. Indeed if more attention were paid to the filtration of air, this standard might well be raised.

Having been provided with a supply of air which is comparatively dust free, our next requirement will be due movement of the air. Movement of the air promotes evaporation from the surface of the body and acts as a stimulant to bodily vigour, whilst stagnant air leads to decreased immunity and increased bacterial growth. Our second demand, therefore, will be that every part of the room should be swept by air currents. The engineer will adopt whatever measures seem necessary for this purpose but the mica anaemometer must indicate movement of the air in every corner of the room under all conditions. The temperature of the air should be in the neighbourhood of 60°F as this is the temperature to which most of us are accustomed indoors. We shall not ask, however, that this temperature be kept uniform throughout. Indeed a " streaky " air, if such were possible, would possess distinct advantages.

Finally, the air should possess a proper degree of moisture. If we accept 60°F as the standard temperature, 70% - 75% relative humidity would represent the correct amount of moisture.

The new standard might briefly be expressed as follows.

(I). A dust-free atmosphere.

(2). Movement of the air in every part of the room.

(3). A temperature in the neighbourhood of 60 F.

(4). Relative humidity. 70% - 75%.

This new standard might not add to immediate personal comfort but it would provide a more wholesome and healthy atmosphere than we are at present accustomed to, even in our best ventilated buildings.